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Project Summary

Cost and Performance Evaluation of In-Plant Trihalomethane Control Techniques

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A study was conducted to evaluate the costs and performance of new technology for reducing trihalomethanes (THM) in drinking water on a bench-, pilot-, and plant-scale. The four Florida plant sites that were selected for study used highly organic surface or ground water supplies and served populations of fewer than 30,000 or fewer than 10,000. Low-pressure membrane processes (ultrafiltration), polyvalent aluminum chloride (PACl) coagulation, flotation, lime softening succeeded by alum coagulation, and conventional lime softening and alum coagulation were investigated for THM reduction at these sites.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The purpose of this cooperative study was to demonstrate the performance and costs of possible new technologies relative to conventional technologies for trihalomethane (THM) control in drinking water. The scope of work was to identify new technology for THM control, identify sites where THM control was needed, and execute in-plant studies with the necessary cost documentation.

The technologies selected for this project were polyvalent aluminum chloride (PACl) coagulation, sequential treatment of alum coagulation preceded by lime softening, membrane processes, and flotation. The selection of sites was coordinated with EPA Region IV and limited to Florida because the varying water supplies and THM problems in that state allowed more technologies to be investigated within the project budget. Coordination with the Florida Departments of Environmental Regulation and Public Health resulted in the survey of more than 50 potential sites. Following plant visits, four sites were selected: (1) The Village of Golf, Florida (VOG), a small lime-softening plant serving 2000 seasonal residents with water containing THM's averaging more than 700 μg/L; (2) the Acme Improvement District (AID), a lime-softening plant serving slightly fewer than 10,000 residents and averaging THM's of 380 μg/L (both AID and VOG are near West Palm Beach, Florida, and use ground waters); (3) the Olga water treatment plant (near Ft. Myers, Florida), an alum plant that uses Caloosahatchee River water, has THM's of 700 μg/L, and serves about 18,000 people; and (4) Venice, Florida (the alternative site), a water treatment plant that serves 13,000 with a blended water from lime softening and reverse osmosis (RO) plants.

Plant Optimization

Optimization of existing plant processes for THM reduction was conducted at all four sites to develop comparable cost data

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and for the benefit of the plants. Bench-scale and pilot-plant membrane processes were investigated at VOG, AID, and Olga. Flotation experiments were conducted at Olga. Pilot-plant sequential treatment was done at AID. Seasonal PACl/alum coagulation was studied on a plant-scale at Olga.

Bench- and plant-scale investigations for plant optimization were conducted at three lime softening plants located in VOG, AID, and Venice, Florida. The bench tests clearly showed that the organic parameters studied--color, dissolved organic carbon (DOC), trihalomethane formation potential (THMFP), and total organic halogen formation potential (TOXFP) could be reduced by increasing softening pH. These plants typically softened at pH 10.3 to a total hardness (TH) of 100 ±50 mg/L as $CaCO_3$ and removed 20% to 30% of the raw color, DOC, THMFP, and TOXFP. The jar tests indicated an additional 1% to 2% DOC removal for every 0.1 pH unit increase in the reaction pH from 9.5 to 11.5. Generally, the THMFP reduction was greater than the DOC reduction because Cl_2 demand was decreased as a result of the lower DOC. The jar test studies also indicated that 20 mg/L or less of alum would increase organic removal 5% to 10% during softening and would not be present in the finished water.

As a result of the bench-scale studies, plant-scale investigations were implemented at each of the lime-softening plants. Similar process changes were made at the three sites, including (1) raising the reaction pH during softening from 10.3 to 11.0-11.3, (2) reducing the chlorine dose by eliminating chlorine as a means of color removal and pH reduction, and (3) adding H_2SO_4 to offset the increased softening pH. At all three sites, THM's were reduced by nearly half, as were TOX and DOC relative to normal operations. Generally, 80% of the color was removed during softening, and hardness was increased 50 to 80 mg/L. THM's at AID and VOG averaged 240 and 330 µg/L, respectively, during the plant test, and were therefore above the maximum contaminant level (MCL). Venice reduced their THM's to 85 µg/L during the plant test and has adopted a high-pH softening process for THM control. The additional cost of high-pH softening ranged from $0.02/1000 gal at Venice to $0.22/1000 gal at VOG. The percentage of unit cost increase for high-pH softening was 2% at Venice, 19% at AID, and 20% at VOG, which corresponded with 32%, 50%, and 45% THM reduction, respectively.

PACl and Alum Treatment

The PACl and alum investigations were made on both a bench- and a plant-scale at the Olga water treatment plant in Lee County, Florida, for both the wet and dry seasons. The organic parameters investigated were DOC, THM, TOX, and color as a result of coagulant dose and pH. Aluminum residuals, turbidity, sludge volumes, and dry-season softening were also investigated.

The raw water color averaged about 57 chloroplatinate units (cpu) during the dry season tests and increased 228% to 130 cpu during the wet season tests. Raw water DOC averaged 19.6 mg/L during the dry season plant tests and increased 9% to 21.4 mg/L during the wet season tests. The raw turbidity averaged 6 NTU during the wet season and 4 NTU during the dry season. The alkalinity and hardness during the wet season were approximately 140 and 110 mg/L as $CaCO_3$, and they increased to 250 and 160 mg/L as $CaCO_3$ during the dry season. The raw water used during both plant tests was a low-turbidity, high-color water that would normally be treated by sweep coagulation for color removal only. Two PACl coagulants—100S,* a sulfate chloride base, and 190, a chloride-based coagulant—plus alum were compared for organic removal.

Jar testing during the wet and dry seasons demonstrated that the optimum coagulation pH was 5.0 to 6.0 for DOC and color removal for all coagulants. PACl 100S was superior to PACl 190 for the removal of DOC and color in jar tests; thus it was selected for plant testing. DOC removal increased with increasing coagulant dose between pH 5.0 and 6.0, but it appeared to approach a limiting value. Coagulant doses of 117 mg/L as alum removed 60% of the DOC and 90% of the color in the wet and dry season jar test. Increasing the coagulant dose to 175 mg/L increased DOC removal 5% to 10% and had less effect on color removal. The percentages of color and DOC removal during the wet season were slightly higher (<5%) than during the dry season for all coagulants. However, the actual DOC concentration and, to a less extent, the color remaining in each season were approximately the same at equivalent conditions for each coagulant. Wet-season THMFP reduction was very similar to DOC removal. The optimum pH range for THMFP reduction was 5.0 to 6.0 for all coagulants, and increasing the coagulant dose increased the THMFP reduction in all jar tests. Doses of 117 to 175 mg/L as $Al_2(SO_4)_3 \cdot 14H_2O$ realized 90% of the maximum THMFP reduction during coagulation.

In all the jar testing, alum generally removed slightly more (<5%) DOC, color, and THMFP than PACl. The seasonal jar tests did not indicate a major difference in coagulant demand for organic removal, possibly because of the small DOC increase during the wet season. Aluminum residuals after coagulation with either PACl-100S or alum were typically less than 0.4 mg/L aluminum and were controlled by coagulation pH. These levels would not cause post-precipitation problems. Removal of DOC and THMFP during coagulation should exceed 60% and be accompanied by more than 90% color removal. Although DOC, THMFP, and color removal vary directly with equivalent coagulation dose and pH, DOC is the better indicator of THMFP than color.

Plant tests using alum and PACl were conducted in the dry and wet season for approximately 30 days each. The aluminum residuals in the distribution system were generally less than 0.2 mg/L. The aluminum residuals of 5 mg/L occurred in the distribution system under the normal plant process of using alum in conjunction with softening. The seasonal plant data demonstrated that finished aluminum residuals are controlled by coagulation pH, which should be 5.5 to 6.5 for minimum aluminum residuals. No significant difference existed between the sludge volumes produced during alum or PACl coagulation during the plant tests for equal operating conditions. The turbidity carryover from the settled water using either alum or PACl coagulation was typically less than 2 NTU and exhibited no differences between the two coagulants. A PACl-100S dose of 80 mg/L was not sufficient to produce a settleable floc during the plant test. An equal alum dose produced a settleable floc.

Softening preceded coagulation during the dry-season plant test. Although softening removed 20% of the DOC and 43% of the color, the succeeding alum or PACl coagulation produced no more color or DOC removal than if coagulation had been used alone. The addition of 1.2 meq/L of alkalinity to the softening process reduced the calcium hardness to only 100 mg/L as $CaCO_3$ although the alkalinity and total hardness were balanced. The softening pH varied from 9.5

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to 10.6, with 10.0 achieving the lowest hardness.

During the wet season, the DOC average reduction was 57% to an 8.6 mg/L residual by PACl and 58% to a 7.0 mg/L residual by alum. The dry season DOC removals averaged 48% (to a 10.1 mg/L residual) for alum and 39% (to a 12.1 mg/L residual) for PACl. This lower reduction during the dry season was due to a higher coagulation pH caused by a hard $CaCO_3$ scale in the reactor. The THM's at the plant tap during the wet season averaged 235 μg/L for PACl and 248 μg/L for alum. The dry-season THM's at the plant tap averaged 204 μg/L for PACl and 175μg/L for alum, which represented a decrease of 13% to 30% in the dry season. However, TOX for alum or PACl were 710 and 714 μg/L during the wet season, and they decreased to 421 and 380 μg/L during the dry season. Color removal was similar to DOC removal, reaching levels of 91% to 94% for PACl and alum during the wet season and 78% to 89% for PACl and alum during the dry season.

The DOC:THM:TOX ratios averaged 1:32:94 during the wet season and 1:16:39 during the dry season. The THM:TOX ratio did not vary as much as the DOC:THM:TOX ratio, since both THM and TOX are directly affected by Cl_2 dose. The THM:TOX ratio was 1:2.9 and 1:2.4 during the wet and dry seasons, respectively.

The operation cost increased from $1.07/1000 gal to $1.16/1000 gal when the maximum alum dose was used during the wet season. This 8% cost increase decreased plant THM's by 72%. The operational cost during the wet season for PACl was $1.62/1000 gal, and similar THM reductions were obtained. The cost of producing water was less during the dry season because of relativley constant labor and power costs and increased production. The plant costs were increased from $0.60/1000 gal to $0.78/1000 gal using the maximum alum dose. This cost increase of 23% reduced THM's by 39%. Dry-season PACl costs were $1.02/1000 gal and decreased THM's by 29%.

Sequential Treatment

Lime softening followed by alum coagulation was investigated on a bench- and pilot-plant scale at the AID water treatment plant. Jar tests were conducted to determine the best sequence of softening and coagulation for THM precursor removal. Pilot plant testing was executed in two unused reactors that were serially connected for the project. The raw water contained no turbidity. The hardness and alkalinity were typically 350 mg/L as $CaCO_3$, with color and DOC values of approximately 40 cpu and 15 mg/L, respectively.

The initial bench-scale sequential treatment work indicated that 60% of the DOC could be removed by sequentially treating AID raw water with softening and coagulation, regardless of order. However, if pH was adjusted to 5.5 during coagulation, this DOC removal was increased 25%. Color removal was 85% to 90% and varied directly with removals of DOC and THM precursors. THMFP was reduced to a range from 167 to 217 μg/L by softening at pH 11.0 and coagulation at pH 5.5, which represented an increased average reduction of 45% relative to softening only at pH 10.3. TOX formation was generally three times THM formation.

The sequential treatment isopleths showed that softening at pH 11.0 averaged 41% DOC, 67% THMFP, 65% TOXFP, and 63% color removal. These were increased removals relative to softening at pH 10.3 (+11% DOC, +3% THMFP, +8% TOXFP, +3% color). Following lime softening with alum coagulation also increased organic removal. The optimum pH and dose were 5.0 to 6.0 and 117 mg/L alum. The DOC, THMFP, TOXFP, and color were reduced an additional 30%, 13%, 23%, and 30%, respectively. Alum coagulation following softening at pH 10.3 increased the percentage of removal for all the organic parameters more than alum coagulation following softening at pH 11. However, the lowest concentrations of DOC, THMFP, TOXFP, and color were from samples softened at pH 11.0 and coagulated at pH 5.0 to 6.0, although these differences were typically less than 5%.

Plant testing of sequential treatment was conducted by softening at pH 10.3 and 11.0 followed by alum coagulation from pH 7.0 to 5.0. The alum dose was varied from 60 to 109 mg/L. The results demonstrated, as did the jar tests, that alum coagulation following softening will decrease the DOC, THMFP, TOXFP, and color relative to softening alone. The maximum DOC and color removals obtained in the plant tests were approximately 70% for DOC and 93% for color. The THMFP and TOXFP were reduced from 20% to 25%. Slightly better removal occurred for all parameters when pH 11 rather than pH 10.3 softening preceded coagulation. The organic removal achieved in sequential treatment indicates that DOC, THMFP, and TOXFP can be reduced an additional 20% to 25% when alum coagulation is used in series with softening. The chemical cost increase would vary from $0.10 to $0.15/1000 gal, which would increase AID O&M cost ($0.35/1000 gal) by 30% to 43%. These data do indicate that, relative to the coagulation testing at other sites, adding softening to a coagulation process could not increase organic removal.

Membrane Processes

Bench-scale (1000 gpd) and pilot-scale (25,000 gpd) investigations of membrane processes were conducted at two sites that used ground water supplies—VOG and AID. Bench-scale investigations were also conducted at one site (Olga) that uses a surface supply. Initially, one RO and six ultrafiltration (UF) low-pressure membranes were purchased and tested for product (permeate) water quality on a bench-scale level. The UF membranes are designed for operation up to 100 psi, whereas the RO membrane is intended to operate at 200 to 250 psi. Bench results from all three sites demonstrated that only two membranes could produce a water from these highly organic sources that would meet the THM MCL and maintain a Cl_2 residual—the Filmtec UF membrane (N-50) and the Filmtec RO membrane (BW 3030).

The nominal molecular weights rejected by each membrane were supplied by each manufacturer and ranged from 40,000 to 100. Bench-scale testing indicated that a molecular weight rejection of 2,000 would typically pass 50% of the raw DOC but only 20% of the color. The resulting product THMFP was generally 800 μg/L for the surface water source and 400 μg/L for either ground water source. The ultrafilter with a molecular weight rejection of 400 passed less than 10% of the DOC and 3% of the color at any site, and it typically produced a THMFP of less than 50 μg/L at the ground water sites and approximately 100 μg/L at the surface water sites. The product was essentially colorless, and the DOC was 2 mg/L or less at all three sites. The color, DOC, and THMFP of the RO membrane were approximately equal to the color, DOC, and THMFP of the best UF membrane. However, the RO membrane operated at 200 psi and rejected species with a molecular weight of 100 or greater as opposed to the UF membrane, which rejected species with a molecular weight of 400 or greater at a pressure of 100 psi. The RO membrane rejected a much

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higher inorganic fraction than did the UF membrane. The RO membrane rejected more than 90% of the total dissolved solids (TDS), total hardness (TH), chloride (Cl^-), and sodium (Na^+) at all sites, whereas the UF membrane inorganic rejection varied from 50% to 70% for the various parameters. Since the N-50 was the membrane that operated at the lowest pressure and still produced a water that met the THM MCL, it was selected for extended operation.

The N-50 ultrafilter was installed at Olga in a bench-scale unit capable of producing 1000 gpd, and it operated for 740 hr over a 45-day period. An operational percentage of recovery and feed pressure matrix was developed to determine the extended study operating conditions. Over matrix conditions of 60 to 120 psi feed pressure and 60% to 90% recovery, product water quality improved at high pressure (105+ psi) and lower recovery (60%). The matrix results indicated the THM MCL could be met if the operational conditions were 105 psi with 60% recovery. At these conditions, product water quality and the percentage of rejections were 1.6 mg/L DOC (92%), 3 cpu color (93%), 172 mg/L TDS (64%), 78 mg/L as $CaCO_3$ TH (65%), 60 mg/L Cl^- (40%), and 68 mg/L as $CaCO_3$ alkalinity (59%) with pH 7.8. During the extended operation, pressure was varied from 60 to 100 psi with recoveries of 60% to 90%. The THM MCL was met for 105 psi and 60% recovery, and for 75 psi and 60% recovery immediately after the membrane was chemically cleaned. The flux decreased with time during the extended study from 18 to 14 gpd/ft^2 over 150 hr of operation. After cleaning with the pressure at 95 psi, the flux declined from 22 to 16 gpd/ft^2, but the product quality remained constant. Flux was independent of recovery during the extended study. The water quality and percentage of rejection for the conditions meeting the THM MCL were 2.7 mg/L DOC (88%), 156 µg/L TOXFP (80%), and 3 cpu color (98%). The inorganic water quality was 145 mg/L TDS (65%), 68 mg/L Cl^- (32%), 85 mg/L as $CaCO_3$ TH (64%), and 7 mg/L as $CaCO_3$ alkalinity (58%). The pH was 7.8, and the water was stable.

A 25,000-gpd mobile UF pilot plant using the N-50 membrane was built in a 30-ft trailer. The UF plant was housed in the 20- by 8-ft rear section of the trailer and equipped for antiscalant feed, acid feed, chlorination, stabilization, prefiltration, and storage as well as UF with variable recovery (50% to 90%) and feed pressure (80 to 120 psi). This plant was installed and operated at VOG for 365 hr from January 2 to March 3, 1985. Initially, an operational test matrix was developed for water quality and flux from varying percentages of recovery and pressure. Product water DOC, color, and THMFP were independent of recovery and pressure over the test conditions and averaged less than 2 mg/L, 1 cpu, and 50 µg/L, respectively. Product water TDS and TH increased with increasing recovery, were independent of pressure, and varied from 25% to 75% of the raw water value. Operating conditions at VOG were set at 90 to 105 psi and 75% recovery to produce a water with a TH of 150 mg/L as $CaCO_3$, essentially no color, and THMFP of 50 µg/L or less. During the VOG operation, the product water quality and the percentage of rejection from the raw water were 1.9 mg/L DOC (88%), 3 cpu color (97%), 27 µg/L THMFP, and 47 µg/L TOXFP. The raw water TDS, TH, and alkalinity were reduced to 195 mg/L (60%), 142 mg/L as $CaCO_3$ (62%), and 135 mg/L as $CaCO_3$ (60%), respectively. The final pH was 7.5, and the water was stable. The product water flux declined 32% during the VOG operation from 20 to 13.4 gpd/ft^2. The water temperature was approximately 25°C and essentially did not vary during the operation.

On March 3, 1985, the UF pilot plant was moved from VOG to AID and operated until May 31, 1985, with an elapsed time of operation of 1020 hrs. A second operational test matrix was developed and showed that color, DOC, and THMFP removal were independent of product recovery and feed pressure over the test conditions (50% to 90% product recovery and 80 to 120 psi). Product water color, DOC, and THMFP were typically less than 2 cpu, 2 mg/L, and 30 µg/L, respectively. TH and TDS removals were independent of pressure and dependent on product recovery, and they varied from 25% to 75% of the raw water value. Long-term operating conditions varied from 90 to 103 psi and 67% to 83% recovery. The product water quality and percentage of rejection from the raw water were 1.5 cpu color (97%), 2.0 mg/L DOC (86%), 50 µg/L THMFP, and 48 µg/L TOXFP. The product water TDS, TH, and alkalinity values and percentage of rejection were 282 mg/L (43%), 187 mg/L as $CaCO_3$ (40%), and 180 mg/L as $CaCO_3$ (37%), respectively. The pH averaged 7.5, and the product was stable.

The UF pilot plant was designed with the membranes in four pressure vessels connected two each in series. The average pressure drop in the first pressure vessel was 32 psi (11 psi/membrane) and 41 psi (13 psi/membrane) in the second pressure vessel. The flux at AID rose slowly from the range of 14 to 15 gpd/ft^2 during the first 150 hr of operation. After a chemical cleaning, it rose to slightly more than 20 gpd/ft^2 and remained there for the duration of the study.

Cost of construction of a UF plant should be slightly less than an equivalent RO plant because of less expensive membranes and lower pressure requirements. Power costs should generally decrease from 75% (100 psi/400 psi) to 50% (100 psi/200 psi). The construction and O&M costs were estimated at $0.29 and $0.47/1000 gal for a 1-MGD UF plant.

Flotation

Bench-scale investigations of dissolved air flotation (DAF) in conjunction with and after alum coagulation of a high-color, low-turbidity water were conducted using a small DAF pilot plant supplied by Komline Sanderson. After contact with DAF, alum floc was found to shear, solubilize, and post-precipitate after sampling was complete. DOC and color removal following DAF of alum-coagulated waters were less than those having only alum coagulation. Foam flotation using alcohol-based surfactants common to the mining industry did not remove DOC from the same high-color, low-turbidity potable water source.

Summary of Results

The DOC removal from each of the processes investigated was different. Lime softening typically removed 10% to 30% of the raw DOC at normal reaction pH's of 9.0 to 10.3. The DOC removal during softening could be generally increased to 40% to 50% by raising the reaction pH. Alum or PACl coagulation should remove 60% to 70% of the raw DOC if the reaction pH is 5.0 to 6.5 and the coagulant dose is adequate—80 to 180 mg/L as $Al_2(SO_4)_3 \cdot 14H_2O$ in the waters investigated. Sequentially treating water with lime softening and alum coagulation would remove 60% to 70% DOC and offers essentially the same removal as alum coagulation. RO at 200 psi or UF at 100 psi with selected membranes will generally remove 90% or more of the initial DOC. No process other than membranes can achieve this high removal for a prolonged period. These general statements concerning DOC removals are supported by the test results of investigations conducted on a low-

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turbidity, high-color surface water and on a low-turbidity, high-color ground water.

Although DOC is a better surrogate than color for THM or TOX formation, DOC cannot be used indiscriminately as a surrogate for chlorinated organic formation. These results and others have suggested that DOC's of less than 4 mg/L following conventional coagulation or softening are required to meet the THM MCL. Indeed, when the DOC was reduced to a range of 5 to 6 mg/L by coagulation, THMFP's of less than 200 μg/L were recorded. The DOC could not be reduced any lower by coagulation or softening of these waters. However, DOC's below 2 mg/L achieved by UF had THMFP's above 100 μg/L. The results indicated that DOC is the best THM surrogate on a process basis. DOC from membrane processes is generally more reactive than DOC from precipitative processes. The THM reduction is significantly greater than the DOC removal because of the reduced chlorine demand, which also reduces THM's. The plant experiences indicate that a 30% reduction in THM is possible if the process is tuned for increasing organic removal and minimizing chlorine dose.

Conclusions

Plant Optimization

- DOC, THMFP, TOXFP, and color are reduced as the reaction pH during softening is increased.
- If the THM's are 150 μg/L or less, the THM and Cl_2 residual MCL can probably be met in a lime-softening plant by increasing the reaction pH and lowering the Cl_2 dose.
- Optimizing a lime-softening plant for THM control will increase product hardness by 75 mg/L as $CaCO_3$, or more.

PACl/Alum Coagulation

- PACl has less base-neutralizing capacity than alum, which would generally be a disadvantage for organic removal from a low-turbidity, high-color water because of the importance of a low-coagulation pH.
- Color, DOC, THMFP, and TOXFP reduction by either PACl or alum coagulation was maximized near pH 5.5.
- Aluminum residuals after PACl or alum coagulation were dependent on coagulation pH and minimized from pH 5.0 to 6.0.
- DOC was a better surrogate parameter for THM and TOX than was color.
- Unit cost depended more on seasonal water demand than on chemicals required for optimum organic removal.
- Preceding either PACl or alum coagulation with lime softening does not increase the organic removal during coagualtion.
- THM:TOX ratios were less variable than DOC:THM:TOX ratios because of the effect of chlorine dose on THM and TOX.
- Alum floc was more settleable at low coagulant doses (80 mg/L) than was PACl floc.
- Alum was slightly superior to PACl for color, DOC, and THMFP reduction.

Sequential Treatment

- The order of lime softening and alum coagulation was not significant for maximizing organic removal if alum coagulation is added to an existing lime-softening plant.
- Alum coagulation added to an existing lime-softening process significantly increases the organic removal and reduces the THMFP; however, lime softening will not increase the organic removal when added to an existing alum coagulation process.

Membranes

- A 150-day pilot-plant UF study of two highly organic ground waters (both of which produced more than 400 μg/L THM's when conventionally treated) produced a finished water that easily met the MCL's for Cl_2 residual and THM's.
- Compared with membranes, no other process has the same practical capacity for the removal of THM precursors.
- The vast majority of THM precursors were rejected by a membrane that has a molecular weight cutoff of less than 2000 but greater than 400.
- The effect of recovery percentage and feed pressure on product water quality was site-specific.
- Flux was site-specific, ranging from approximately 20 to 10 gpd/ft^2, and it was generally independent of the recovery percentage.
- Caloosahatchee River water needs more elaborate pretreatment than single-pass sand filtration to maximize N-50 permeate flux. Flux values during the extended study were 12 to 18 gpd/ft^2, and they decreased continuously with time of operation.
- N-50 permeate quality is a function of feed pressure, percentage of recovery, and membrane surface condition. The best inorganic and organic rejection occurred at the highest pressures, the lowest recoveries, and the cleanest membrane condition. With the Caloosahatchee water, the THM MCL was met only at the 105 psi, 60% recovery and the 75 psi, 60% recovery conditions for a cleaned membrane. Membrane surface conditions appear to be as important as the pressure-recovery setting for organic rejection. Poor permeate quality during extended operation was primarily due to membrane fouling.
- Inorganic parameters such as TDS and TH were reduced approximately 40% by UF at approximately 100 psi and 75% recovery.
- The product water at VOG, AID, and Olga exhibited low DOC and color values that would not require additional color removal through chlorine bleaching.
- The organic quality produced during the VOG and AID UF pilot-plant tests were independent of the percentage of recovery and feed pressure for the test conditions.
- The inorganic quality produced during the UF pilot-plant tests at VOG and AID were independent of the feed pressures and improved as the percentage of recovery decreased.
- UF with the N-50 membrane produced a stable, noncorrosive water.
- The operation of the UF membrane pilot plant required less effort and skill than the operation of the other processes investigated, and it produced a vastly superior organic water quality.

Flotation

- DAF of alum sludge caused floc shear and post-precipitation. It removed no more organics than did conventional alum coagulation.
- Foam flotation using conventional alcohols common to the mining industry removed no DOC from the raw water.

Recommendations

- PACl studies should be expanded to include high-turbidity and/or low-alkalinity waters.

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- DOC could be used as a surrogate for THM formation on a site-specific basis.
- Specific organic rejection by membrane processes should be investigated to include priority pollutant removals and other organics capable of adverse health effects.
- Cost and performance information on membrane processes should be made available to the water utility industry as soon as possible so that they can be considered in planning for plant expansion or new plant construction.
- A national survey of membrane plants should be conducted to determine (1) the cost of construction, operation, maintenance, (2) operating conditions and problems, (3) raw and finished water quality, and (4) brine disposal and membrane life.
- Further bench and pilot-plant testing using UF and RO membranes should be conducted on surface and ground waters of varying organic quality to ascertain the relationships among water quality, recovery, pressure, flux, membrane cleaning, membrane materials, and membrane life.
- Newly constructed membrane plants using raw waters normally treated by lime softening or coagulation should be monitored for cost, water quality, and operating conditions, and that information should be published for the water utility industry.
- A permanent membrane plant that uses UF and RO should be constructed, operated, and monitored for 2 to 5 years to provide for a small community (fewer than 3,000 residents) water that does not exceed the THM MCL. Such a project could (1) establish membrane processes as a practical means of organic control, (2) provide the best possible data on cost, water quality, and operation, and (3) demonstrate the ease of operation, modular expandability, operator skill required, and consistency of membrane processes.
- A mobile, pilot-plant-scale, hybrid system of low-pressure RO and UF membranes should be constructed and operated to assess organic control and production of waters with suitable hardness values. Also, saltwater-intruded, high-organic waters could be studied, particularly the coastal waters.
- Research and development should continue on molecular-weight rejection by membranes. This work has indicated that significant THM precursor rejection is accomplished between molecular-weight rejections of 400 and 2000. A membrane that has a molecular weight rejection greater than 400 may have as good a THM precursor rejection and be less expansive to operate.

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The complete report, entitled "Cost and Performance Evaluation of In-Plant Trihalomethane Control Techniques," (Order No. PB 86-130 515/AS; Cost: $34.95, subject to change) will be available only from:
National Technical Information Service
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The EPA Project Officer can be contacted at:
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Penalty for Private Use $300

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